

Observations and Modeling of the West Florida Continental Shelf Circulation

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LONG-TERM GOALS

My long-term goal is an improved understanding of how physical processes affect material property distributions on continental shelves. These include biological (red-tide algae and fish larvae), chemical (nutrients), and geological (resuspended sediments) properties, and the physical responses of sea level, currents, temperature and salinity.

OBJECTIVES

To achieve this goal I must accomplish a related set of objectives. In logical order, these are. 1) I am developing descriptions of the tidal, synoptic, seasonal, and inter-annual varying circulations on the West Florida Continental Shelf (WFS). 2) Along with descriptions, I am developing quantitative understandings of how various external forcing functions affect the WFS circulation. 3) I am determining how these processes affect the along and across-shelf transports of materials, with emphasis on the frictional boundary layers. 4) Given both large seasonal transitions and inter-annual variations, I am assessing the relative importance of local versus deep-ocean forcing in effecting WFS water properties. 5) For local forcing, I am assessing the relative influences of the surface buoyancy (heat and fresh water) and momentum (wind stress) fluxes. 6) For deep-ocean forcing, I am looking into how and where the Gulf of Mexico Loop Current impacts the WFS. 7) I am relating these physical factors to questions of geological, biological, and chemical importance; for example, storm surges, sediment redistributions, nutrient distributions, species migrations and successions, primary productivity, red-tides, and how all of these factors affect inherent optical properties (IOPs). 8) Since these objectives require sampling over various time and length scales using an assortment of instruments, I am working toward a WFS Autonomous Ocean Sampling Network (AOSN) site south of Tampa Bay that may be useful for naval defense related experimentation and for a regional contribution toward and integrated, sustained, coastal ocean observing system. 9) To support AUV operations, sensor developments, prognostic physical and biological models, and to provide useful public data products, I am expanding the capability for real-time data through moorings, floats, and other techniques. 10) Finally, I want to observe the responses of the near bottom log-layer region across the inner-shelf to assess sediment resuspension events and their effects upon water column IOPs.

APPROACH

My approach is a coordinated program of *in situ* measurements and numerical circulation models. With colleagues, resources have been marshaled from several projects. The *in-situ* measurements have

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14. ABSTRACT My long-term goal is an improved understanding of how physical processes affect material property distributions on continental shelves. These include biological (red-tide algae and fish larvae), chemical (nutrients), and geological (resuspended sediments) properties, and the physical responses of sea level, currents, temperature and salinity.				
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consisted of moored arrays complemented by hydrographic cruises. The array configurations have included bottom and surface mounted acoustic Doppler current profilers (ADCP) for currents. Our bottom moorings generally include temperature/salinity (T/S), and pressure sensors, and a smaller subset of these may also include sediment resuspension packages (near bottom acoustic current profilers and optical instruments). The surface moorings generally include surface meteorological instruments and a vertically distributed set of either T/S or T sensors. At its peak a total of 13 moorings were deployed with emphasis on the inner-shelf. Presently there are six moorings deployed, two bottom mounted and four surface buoys. The surface buoys have real time telemetry.

The coordinated numerical modeling is based on applications of the primitive equation Princeton Ocean Model (POM) of Blumberg and Mellor (1987). The present model domain extends from west of Mississippi River to the Florida Keys with one open boundary arching between. Horizontal resolution varies from about 6 km along the open boundary to 2 km near shore, and 21 sigma layers span the vertical. Baroclinic hindcast simulations (all quantitatively compared with data) use NCEP reanalysis winds and surface heat fluxes (with a flux correction to a satellite SST product) and inputs from seven rivers. Nowcast/forecast simulations use ETA winds. Nowcast/forecasts are presently barotropic, awaiting an improved surface heat flux product to convert these to baroclinic.

WORK COMPLETED

I initiated a WFS circulation study in 1993 in cooperation with the USGS Center for Coastal Geology. This expanded in 1995 with MMS and ONR support. The State of Florida approved a long-term plan for a Coastal Ocean Monitoring and Prediction System (COMPS) for real-time currents and surface fluxes offshore, and sea level and winds at the coast. USF, in partnership with others, was awarded an ECOHAB (Ecology of Harmful Algal Blooms) regional field study for the WFS by NOAA/COP, and this evolution helped to facilitate the present efforts.

Measurements began with a mid-shelf ADCP from 10/93 to 1/95. These data defined the relevant time scales and showed a seasonal cycle in the circulation. Weisberg et al. (1996a,b) and Black (1998) present some of these findings. This was followed by a trans-shelf array of ADCPs deployed between the 300m and the 30m isobaths over the 8-12 month period 1/95-2/96. Data are reported in Weisberg et al. (1997) and Siegel (1998). They show an inner-shelf region where responses to synoptic weather forcing are well-defined, contrasted with an outer-shelf region where interactions with the deep-ocean may be controlling. Meyers et al. (2001) describes the outer-shelf features.

To look more closely at the inner-shelf, ADCPs were deployed off Sarasota, FL on the 20m and 25m isobaths in 11/96. They show the three-dimensional nature of the inner-shelf and the importance of baroclinicity even in shallow water. Seasonally, we observe a modulation of the across-shelf transports in response to wind forcing as the surface and bottom Ekman layers adjust to stratification. An upwelling/downwelling response asymmetry is demonstrated by the Weisberg et al. (2000a) comparison between *in-situ* data and a numerical model simulation for April 1998 when stratification was well developed. Upwelling favorable winds produce disproportionately larger responses in both the sea level and currents than downwelling favorable winds, and this is explained on the basis of the streamwise component of relative vorticity. For downwelling favorable winds, the buoyancy torque due to isopycnals bending into the sloping bottom opposes the tendency by the tilting of planetary vorticity filaments by the vertically sheared coastal jet. This thermal wind effect negates the need for large dissipation of relative vorticity by the across-shelf flow in the bottom Ekman layer. The opposite occurs for upwelling favorable winds. Buoyancy torque adds constructively with planetary vorticity filament tilting requiring larger dissipation of relative vorticity by the bottom Ekman layer. By

enhancing (upwelling) or suppressing (downwelling) the bottom Ekman layer the entire response is reduced or increased, respectively.

Satellite imagery plays an important role in our work. Weisberg (1994) related SST patterns to Loop Current influence on the WFS. Weisberg, et al. (2000b) report on an upwelling case study using satellite imagery, *in-situ* data, and a numerical model simulation. The case study winds were calm for several days prior to a wind-driven upwelling event, allowing us to view the response as an initial value problem. The Ekman/geostrophic route to spin-up is observed, and supporting dynamical analyses show the ageostrophic effects of the boundary layers under either stratified or constant density settings. Coastline geometry changes cause large three-dimensional effects, and the findings of this paper provided a physical basis for our WFS ECOHAB proposal hypothesis.

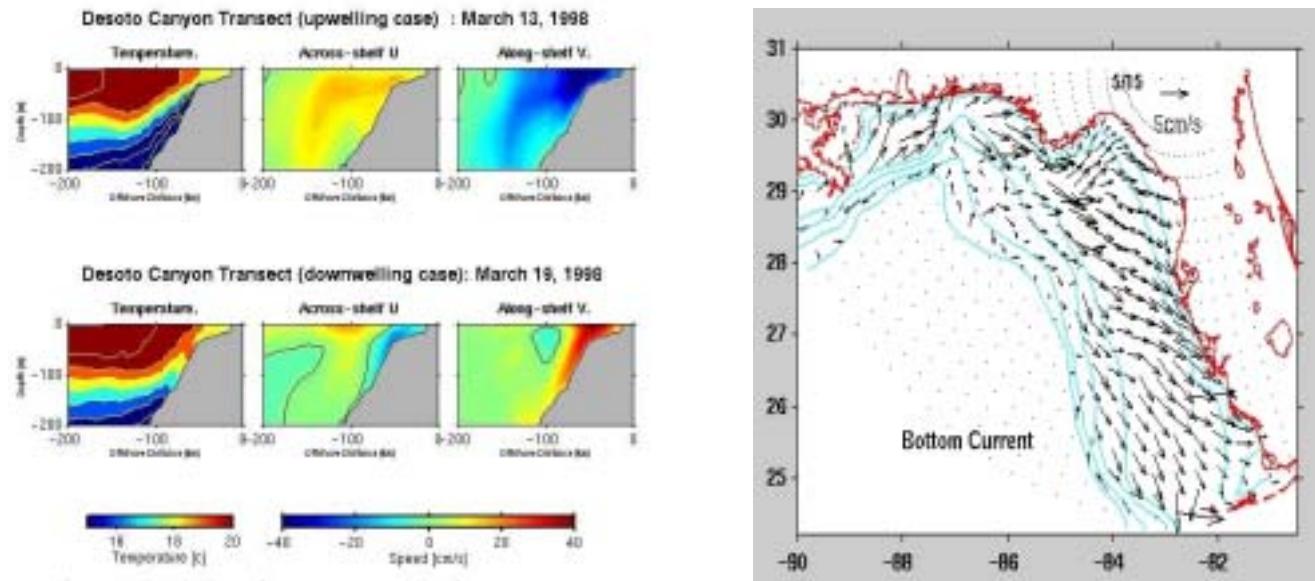
Our numerical model applications began with preliminary warm up exercises. Yang and Weisberg (1999) examined the WFS response to climatological monthly mean winds showing seasons with upwelling and downwelling tendencies. Yang et al. (1999) describes Lagrangian experiments to help explain why surface drifters deployed in the northern WFS avoided the inner-shelf south of Tampa Bay. Li and Weisberg (1999a,b) considered the kinematics and dynamics, respectively, for barotropic responses to upwelling favorable winds. Yang and Weisberg (2000) provide hurricane storm surge simulations for category 2 and 4 storms making landfall at various locations along the west Florida coast. We have now evolved to more realistic simulations. He and Weisberg (2001) consider the WFS circulation and temperature budget for the 1999 spring transition in which quantitative comparisons are made between *in-situ* data and model results. This paper confirms the hypothesis of Weisberg et al. (1996) that surface heat flux is an important contributor to the seasonally varying shelf currents, and it accounts for the so called “Green River” of Gilbes et al. (1997) on the basis of local forcing, independent of the Loop Current. He and Weisberg (2002a) is a WFS tide model quantitatively compared with *in-situ* currents and sea level data. He and Weisberg (2002b) consider a Loop Current intrusion case study with *in-situ* data demonstrating the Taylor-Proudman theorem constraint on across-slope penetration. The Loop Current may impact the shelf currents under special conditions (when it contacts the WFS southwest corner where the isobaths converge), and this is a topic of Weisberg and He (2002), where we consider the relative importance of local versus deep-ocean forcing in accounting for anomalous water properties observed in spring through fall of 1998. We show, by systematic experiments, with and without Loop Current influence, how and where deep, nutrient rich waters upwell onto the WFS and how they are transported to the near-shore. In so doing we also confirm the hypothesis advanced by Hetland et al. (1999) on Loop Current southwest corner impacts. Walsh et al. (2002) then uses these circulation fields to grow plants under varying light and nutrient conditions as a successful example of our first fully baroclinic, coupled physical/biological model for the WFS. Also in review is He and Weisberg (2002c) which describes the circulation and temperature budget for the 1998 fall transition. In addition to the POM code we implemented a Finite Volume Model code (C. Chen, personal communication), and we are familiarizing ourselves with the ROMS code (H. Arango, personal communication). R. He attended the data assimilation symposium held by A. Bennett at OSU this past summer.

In summary, over the past year: 1) We completed a two-year deployment of the combined COMPS/ECOHAB/HyCODE moored array, plus monthly hydrographic cruises, leaving in place a reduced array for long-term monitoring. 2) We published four papers, have three in press, and we submitted three other manuscripts. Additionally, several articles are either in press or submitted for proceedings volumes. 3) We have an operational, web-based, nowcast/forecast model. 4) We have a high resolution model that links the Tampa Bay and Charlotte Harbor estuaries with the WFS. 5) This

high resolution finite volume model is also being used (with flooding/drying provision) for hurricane storm surge simulations, building on our previous low resolution studies with the POM.

RESULTS

Significant new findings over the past year are as follows. 1) The mid-shelf, spring cold tongue waters are of both deep and shallow water origin. Since WFS nutrients are of deep-ocean and land origin, the observation of cold water, in and of itself, is neither indicative of upwelling nor of potentially high primary productivity. 2) The upwelling of deep, nutrient rich waters depends on a combination of local and deep-ocean forcing. Deep-ocean processes (the Loop Current and its eddies, for instance) set the height of material isopleths at the shelf-break, thereby affecting the potential for these properties to broach the shelf-break, but local forcing is generally required to upwell these properties onto the shelf. 3) Once on the shelf both local and deep-ocean effects are instrumental in distributing materials across the shelf, with the bottom Ekman layer being the primary conduit for across-shelf transport. 4) Local geometry is very important. There are preferred upwelling sites and since the shelf-break is somewhat deeper in the Florida Big Bend than in DeSoto Canyon, the Big Bend is an important site for intrusions of nutrients that eventually are advected to the Tampa Bay to Charlotte Harbor region. 5) Given these physical findings we were able to account for the anomalous conditions of 1998 and to explain the primary productivity in the context of a coupled physical/biological model. 6) R. He completed his Ph.D. As examples of findings 2) and 3) the graphics shown below provide across-shelf sections of temperature, and along- and across-shelf velocity components for an upwelling (March 13, 1998) and downwelling (March 19, 1998) sequence in response to local forcing only (left hand panels) and the bottom Ekman layer velocity field on May 15, 1998 in response to both local and Loop Current forcing.



IMPACT/APPLICATIONS

WFS physical oceanography is essential to WFS biology and optics. The 3-D, time dependent WFS circulation responses to local and deep-ocean forcing sets the stage for chemical, geological, and

biological properties sampled by sensors aboard AUVs, or flown on aircraft or satellites. Moreover, the bottom Ekman layer, generally not sampled by remote techniques, is the principle conduit for the across-shelf transport of biologically important materials. Thus, our work has significantly impacted WFS coupled physical/biological models and the sampling strategies for multidisciplinary variables.

TRANSITIONS

The physical/biological modeling efforts will eventually transition to a WFS red-tide forecast model as part of the NOAA MERHAB Program. Real time, inter-net accessible measurements and models are also being used for emergency preparedness as part of the USF COMPS.

RELATED PROJECTS

We are interacting with NOAA sponsored scientists to the south in Florida Bay (P. Ortner) and to the north in the Florida Big Bend (W. Sturges). The NOAA/EPA ECOHAB Program is co-located with our work (other P.I.s include J. Walsh, G. Vargo, K. Steidinger, G. Kirkpatrick). For HyCODE we are also interacting with K. Carder, R. Maffione, and others, and for the larger Gulf of Mexico arena we are interacting with Dynalysis (R. Patchen), Princeton (G. Mellor), and RSMAS (C. Mooers). New for the coming FY is a southeast regional consortium of scientists from North Carolina, South Carolina, Georgia, and Florida (SEA-COOS) working toward an integrated, sustained, coastal ocean observing system. A parallel development at USF (C. Lembke, R. Byrne, and R. Weisberg) is the Bottom Stationed Ocean Profiler (BSOP) for mapping hydrographic fields using profiling floats. Between the HF-radar to be provided by SEA-COOS and internal T/S fields from BSOP, we anticipate having real time data fields along with our present point measurements for assimilation into our models.

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